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Analysis of characteristic parameters of commercial photovoltaic modules

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Abstract

Photovoltaic energy generation can still be considered as being developed in the world, representing a growing market, especially after the year 2000. The main objective in this work is to present the characteristics for different technologies and manufacturers of commercial photovoltaic modules, based on their electrical parameters. For this purpose, data extracted from datasheets of 281 photovoltaic modules from different types and manufacturers were used. This database gives a good idea of the photovoltaic market.

Selection and/or peer-review under responsibility of ISES.

Keywords:Solar photovoltaic, photovoltaic modules, electrical parameters

1. Introduction

Photovoltaic solar energy is a type of electricity generation that has been developing at high rates in recent years. Cost reduction due to technology advances has been the main responsible factor for this growth. Moreover, the low environmental impact, its modular characteristics and low maintenance costs are also factors which have contributed to this growth, which have been mainly lead by grid-connected systems, that started increasing fast after the year 2000. Fig. 1, published by the International Energy Agency (IEA) [1], shows the installed power capacity worldwide and the predominance of the grid-connected PV applications when compared to isolated systems.

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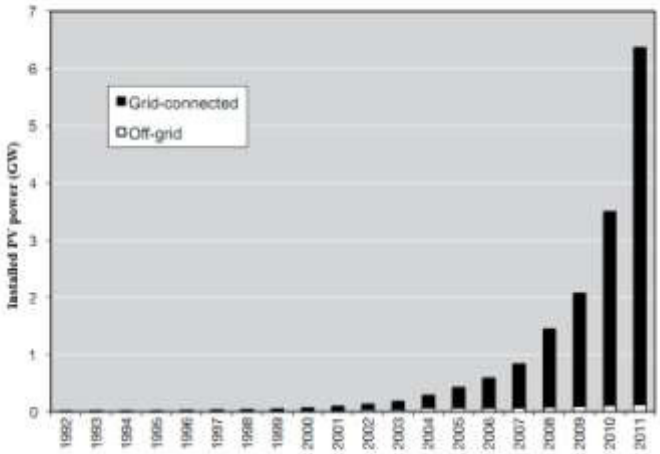

Fig. 1. Installed capacity of grid-connected and off-grid systems PV applications.

SCHOTT Electricity [2] cite a wide variety of photovoltaic installations with different applications, such as residential, industrial and isolated systems, focusing on their economic viability. Their analysis involved the cost of photovoltaic power generation and the cost of energy in the world. They projected that the competitiveness of photovoltaic would start in 2008, coming to completely competitive prices with traditional energy at peak hours in 2020.

According to the European Photovoltaic Industry Association (EPIA) [3], the global cumulative installed capacity of photovoltaic modules was 102 GW in 2012. The most important countries were Germany with 32.4 GW, Italy with 16.4 GW, China with 8.3 GW, USA with 7.7 GW, and Japan with 6.9 GW. The worldwide production capacity in 2012 was 56 GW, being 82 % of crystalline silicon modules, 15 % of thin film modules, and 3 % of high efficiency modules. The relative amount of thin film was 31 % of Cadmium Telluride (CdTe), 26 % of Copper Indium Gallium Selenide (CIGS), and 43 % of amorphous silicon.

Moosavian et al. [4] made an analysis of the distribution of solar energy in several regions of the world, and discuss in detail how the implementation of PV technology has proceeded in some countries. They highlight the importance of public policies in the form of feed-in-tariff, renewable portfolio standards, investment tax credits, pricing laws, production incentives, quota requirements, trade systems, and other incentives in the photovoltaic development.

In this favorable context, this work aims to study the electrical characteristics of some of the current commercial modules existent in the market, to describe the state-of-the-art of this technology. The collected and analyzed data reflect the current applications, since the electrical characteristics of modules are designed to supply the grid-connected systems. The work presents some graphical representations of the parameters of PV modules, that facilitate the understanding of this technology, and contributes to the design of the PV systems applications, since it allows a quick access the data of the some currently available photovoltaic module technologies.

2. Description of the research

The definition of the relevant manufacturers of photovoltaic modules was the first step to develop this overview. To have an objective way of analyzing the technologies produced by these manufacturers, the selection criteria was to get the datasheets of all modules with high conversion efficiency, because they represent well the technology development. To compare the manufacturers the Solar Plaza ranking [5] was used. This site ranks the most efficient PV modules by technology: monocrystalline, polycrystalline and thin film. After this choice, the catalogs of photovoltaic modules developed by five manufacturers for each of the three technologies were consulted. Manufacturers that did not have sufficient available datasheets on their sites were excluded. For the selected manufacturers, all modules which had datasheet in the Internet were used as information source for this research, thus composing a database of electrical characteristics with a quite large quantity of technical information. The selected manufacturers and the number of their modules used in this research are shown in Table 1.

Table 1. Photovoltaic modules available in the database.

Manufacturer	Tecnology	Number of Modules
Kyocera	Monocrystalline/Polycrystalline	62
Yingli	Monocrystalline/Polycrystalline	20
Atersa	Monocrystalline/Polycrystalline	34
China Sunenergy	Monocrystalline/Polycrystalline	38
CNPV Solar	Monocrystalline/Polycrystalline	66
Sanyo	Monocrystalline/Polycrystalline	26
Avancis	Thin Film	11
Global Solar	Thin Film	9
Solar Frontier	Thin Film	4
Global Solar	Thin Film	5
Nanosolar	Thin Film	5

For thin film modules it is important to highlight the type of cell. Avancis and Solar Frontier use the Copper Indium Selenide technology, Global Solar modules are flexible CIGS (Copper Indium Gallium Selenide), and Nanosolar rigid CIGS modules. To characterize these devices, values of the main electrical parameters and other variables such as, fill factor, efficiency, and the temperature coefficients were compared. The study shows how the technological development of photovoltaic modules has been adapted to supply the grid-connected PV applications market.

3. Results

All data collected during the development of this work were organized graphically. Thus, it is possible to visualize simultaneous data about the performance of a large number of PV modules. Furthermore, the main electrical characteristics analyzed here are defined and briefly discussed hereafter.

3.1. Efficiency

One of the most fundamental characteristic of an energy conversion device is its efficiency, because it determines its ability to transform one type of energy in another type. With the PV modules, it is not different, and the efficiency is even more relevant, because the commonly used technologies have relative low values of efficiency and high costs.

Kazykov et al. [6] developed a great panorama about the physical and electrical characteristics of PV modules focusing in efficiency. They cite several modules with efficiencies ranging from 13.7 to 14.4 % for poly and monocrystalline silicon technologies, respectively, while the thin film technology range is 6.o to 11.0 %. The analysis of the photovoltaic modules efficiency from different types and manufacturers gives a good idea about the performance of different equipment available in the market. In addition, this survey reflects the best values that the current development of technology achieved at the market. Fig. 2 shows the energy conversion efficiency for all photovoltaic modules used in this study, classified according to module peak power.

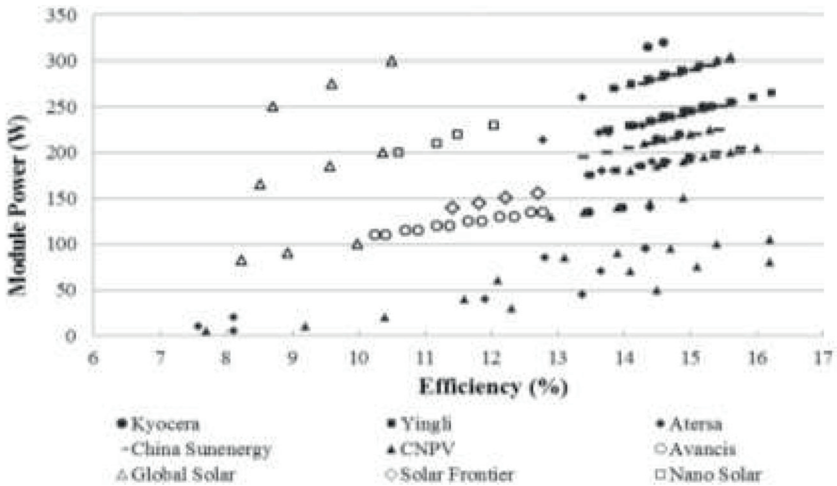

Fig. 2. Analysis of module efficiency.

In Fig. 2, each point represents a module produced by one manufacturer. Manufacturers of mono and polycrystalline modules are identified by dark markers and the thin film by white markers. The efficiency values for mono and polycristalline modules are concentrated between approximately 13.5 % and 15.5 %. This analysis indicates that, for the current status of PV modules, the expected market values of energy conversion efficiency are in this range. It should be emphasized that these efficiencies are related to standard test conditions, which consider 25 °C of cell temperature, air mass of 1.5, and irradiance of 1.000 W/m². It is also noted that the efficiency decreases with the reduction of PV module rated power in mono and polycrystalline modules. This reduction is observed because the smaller modules have typically larger areas without cells. The PV thin films modules presented in Fig. 2 have typical peak powers ranging from 80 Wp to 300 Wp, and efficiencies distributed in the range between 8 to 13 %.

The same analysis of efficiency was conducted only for Kyocera modules, because in this particular case the manufacturer presents some datasheets for discontinued modules. This information is shown in Fig. 3.

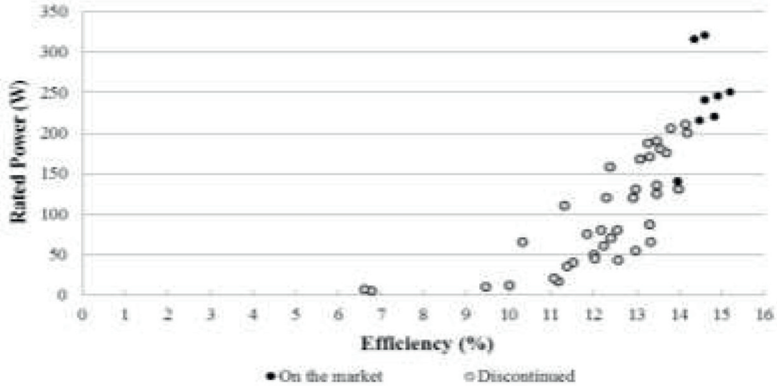

Fig. 3. Analysis of Kyocera modules efficiencies.

The efficiency and the rated power of the modules from this manufacturer show a considerable increase. The power increase is mainly explained by the requirement of grid-connected applications. Regarding efficiency, which presents an almost linear increase, this can be explained by the development of cell fabrication technologies, modules with more area filled by cells, and the improvement in metallic contacts, among other factors. Those improvements made the efficiency of these modules increase from 10 % to 15 %. Note that the currently Kyocera modules efficiency range is between 14 and 15 %.

3.2. Open-circuit voltage, short-circuit current and fill factor

Besides the efficiency, two other electrical characteristics are fundamental for the analysis of PV modules, which are short-circuit current and open-circuit voltage. The open-circuit voltage of the module depends mainly on the number of cells connected in series, being the voltage of each cell normally around 0.6 V. Fig. 4 shows the values of open-circuit voltages for the selected modules.

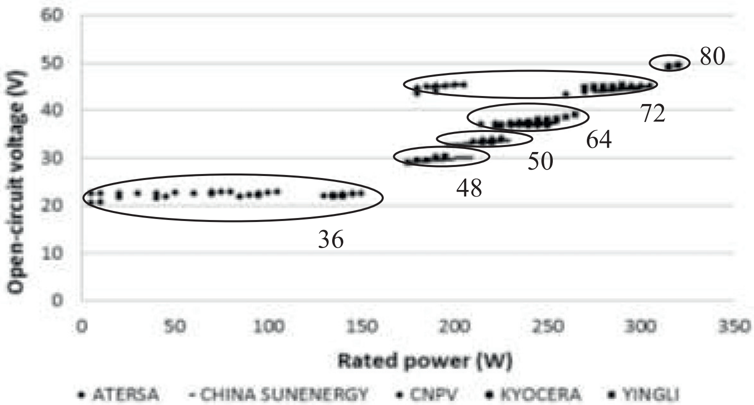

Fig. 4. Analysis of module open-circuit voltages.

The open-circuit voltage values are distributed into sets of equal values for a large power range, according to the number of cells which constitute the module, and are limited to a specific range between

21.6 V (36 cells) and 49.5 V (80 cells). Another interesting aspect is the large number of modules with 36 and 72 cells. This can be explained for these modules are ideal to load battery systems with 12 V and 24 V, respectively.

Further investigation with this database refers to the short-circuit currents shown in Fig. 5. The majority of the tested photovoltaic modules have currents between 7 A and 9 A. This analysis shows market dominance of cell sizes of 15.6 cm x 15.6 cm (243 cm^2). The second group of modules are manufactured with 12.5 cm x 12.5 cm (156 cm^2), while the rest of them are not manufactured with complete cells, but only with portions of them. It should also be noted that a significant variation in current values were found even within a specific group of cells; for example, solar cells of 243 cm^2 present a short-circuit current range from 8 to 10 A. This means that some modules are able to produce more current with the same area, which makes them more efficient.

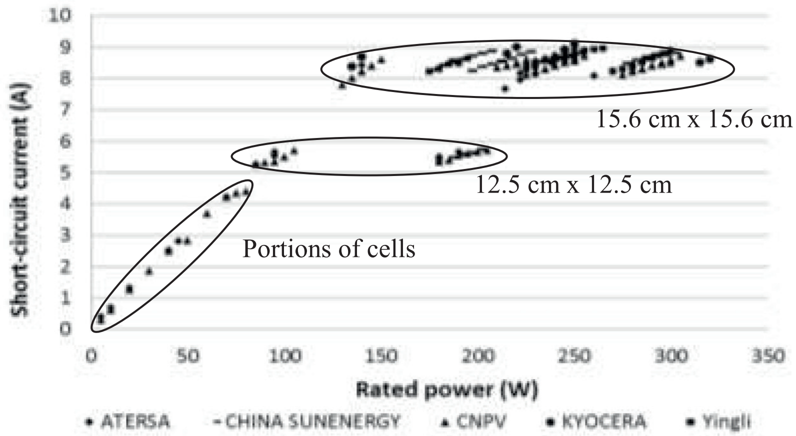

Fig. 5. Short-circuit current as a function of rated power.

Fig. 6 presents the short-circuit current per square meter of module area. As expected, the module current density is nearly a linear function. The PV modules analyzed in this work are able to produce from 260 to 340 A/m². The average value obtained for PV modules was 306.6 A/m², while the relationship between short-circuit current and cell area is 340.56 A/m².

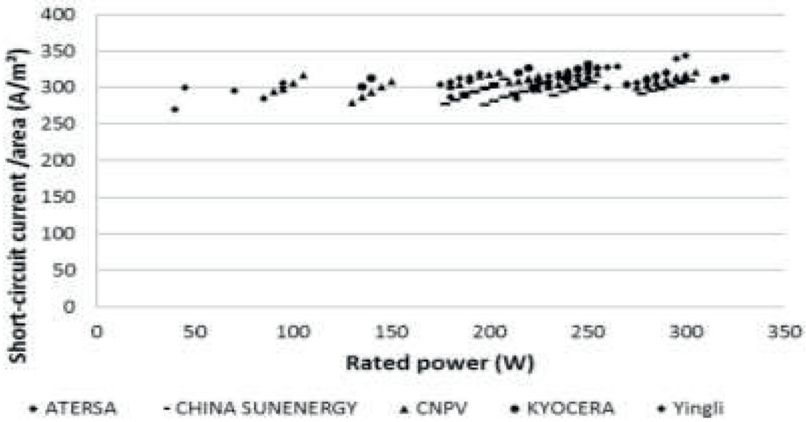

Fig. 6. Short-circuit current per square meter of module area.

Another analysis made was about the fill factor, which is the ratio of the maximum output power (Vpmax x Ipmax) versus its 'dummy' output power (Voc x Isc). This is a key parameter in evaluating the performance of a PV module. The selected modules, with mono and polycrystalline technologies, have a fill factor above 0.70, as can be seen in Fig. 7. High values of fill factor indicate that the modules have good electrical characteristics.

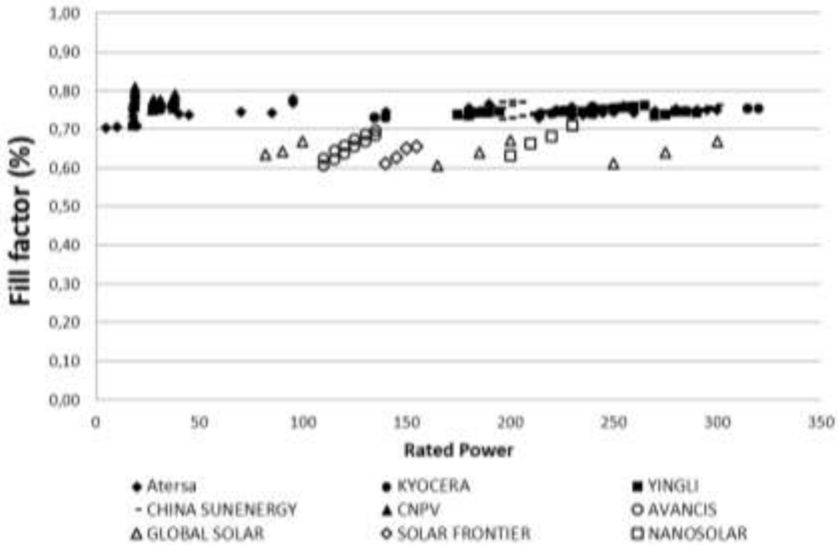

Fig. 7. Module fill factor as a function of the rated power for different PV module technologies.

Based on the data collected, the fill factor for the mono and polycrystalline technologies lay almost entirely between 70 and 80 %. The thin film modules have this characteristic in the range from 60 % to 70 %. These values reflect the influence of technology type in the maximum power point, and show how the thin film modules have an I-V curve shape farther from the ideal.

Comparing the values of short-circuit currents and open-circuit voltages with their respective rated values at maximum power, it is possible to obtain a correlation between these parameters, as shown in Fig. 8.

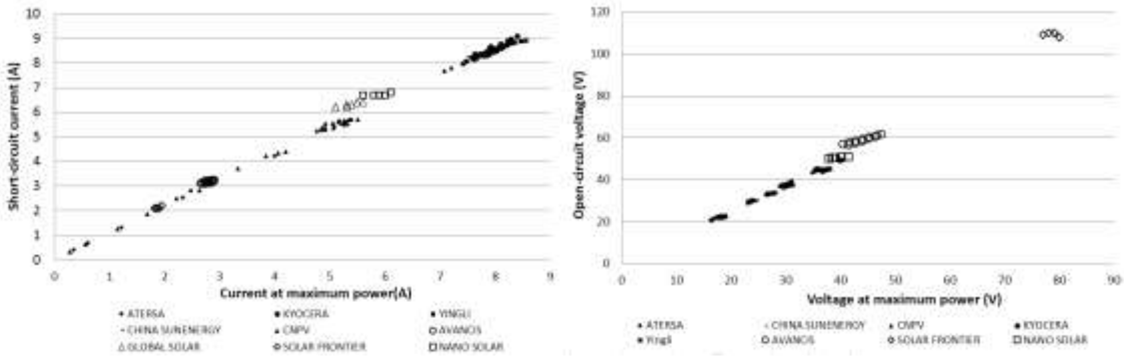

Fig. 8. Correlation between: (a) short-circuit currents and maximum rated currents; (a) open-circuit voltages and maximum rated voltages.

The linear trend of these variables and the low dispersion values demonstrate high ratios between the magnitudes. For mono and polycrystalline technologies, the average value obtained for the relationship between the maximum rated current and the short-circuit current was 81.0 %, with values concentrated in the range of 78 and 83 %. JIANG et al. [7] analyzed this factor for various conditions of irradiance and temperature, with monocrystalline modules, at the solar simulator, and their study showed mean values of 81.4 %. ORIOLI et al. [8] proposed a new method of analysis of the electrical parameters of modules, and the values presented in their study were 80.4 %.

Analyzing again the mono and polycrystalline technologies, the quotient of maximum rated power voltage and open-circuit voltage of the modules analyzed here, resulted in an average value of 92.8 %, ranging from 90 % to 95 %. The average values of these quantities presents in ORIOLI et al. [8] is 93.1 %. These comparisons show that the range of values between these quantities is well established, having a small variation between different modules. Higher values of these quotients indicate better performance of the equipment, representing an improvement of the I-V curve shape.

It is also observed that the thin film modules present values that are slightly above those for the mono and polycrystalline technologies.

3.3. Temperature coefficients

The temperature coefficients are important because they demonstrate the performance decrease of the module with increasing temperature. This characteristic is especially important in the analysis of performance between technologies. The first coefficient shown in Fig. 9 indicates the percentage decrease in the module maximum power for each degree Celsius of temperature increase.

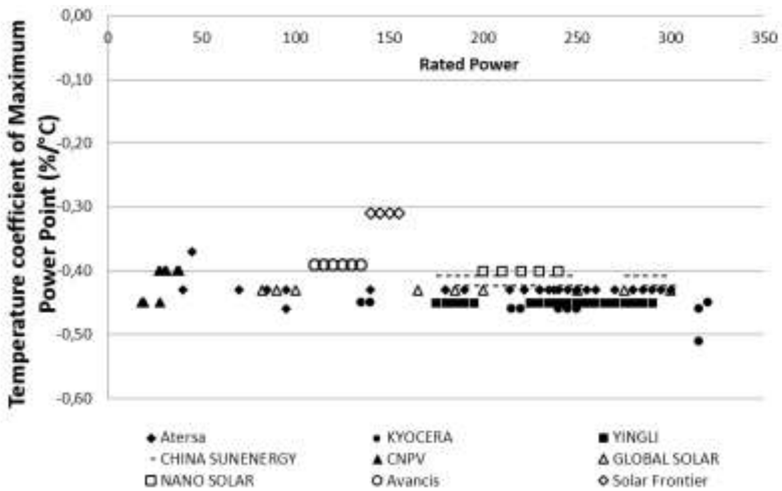

Fig. 9. Effect of temperature on the maximum power.

Fig. 9 shows that the maximum power temperature coefficient values are mainly between -0.4 and -0.45 %/^{0}C. Modules of thin film technologies have better coefficients than traditional technologies, among which the CIS technology presents the best thermal performance. The modules manufactured by Solar Frontier presented temperature coefficients considerably lower compared to the other manufactures.

The temperature coefficient for short-circuit current is shown in Fig. 10. The modules with conventional technologies have higher values than thin film technologies. Global Solar modules have a negative coefficient, which means when there is an increase in temperature, there is a reduction in the short-circuit current.

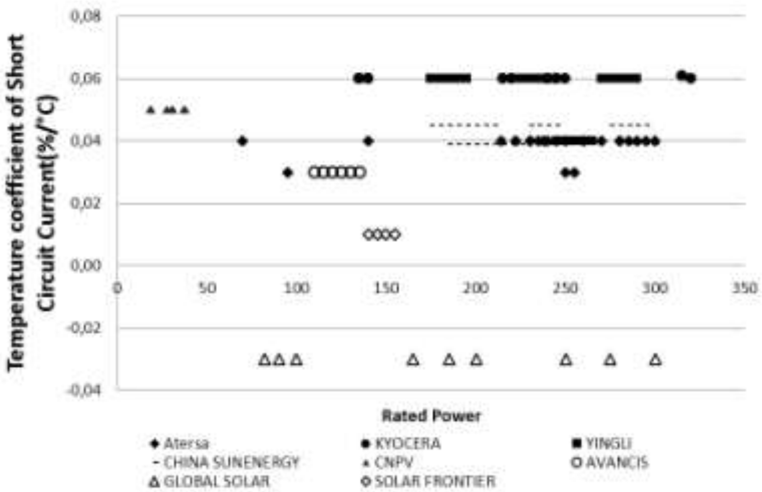

Fig. 10. Effect of temperature on the short-circuit current.

The final analysis is the coefficient of variation of the open-circuit voltage with temperature, which is shown in Fig. 11.

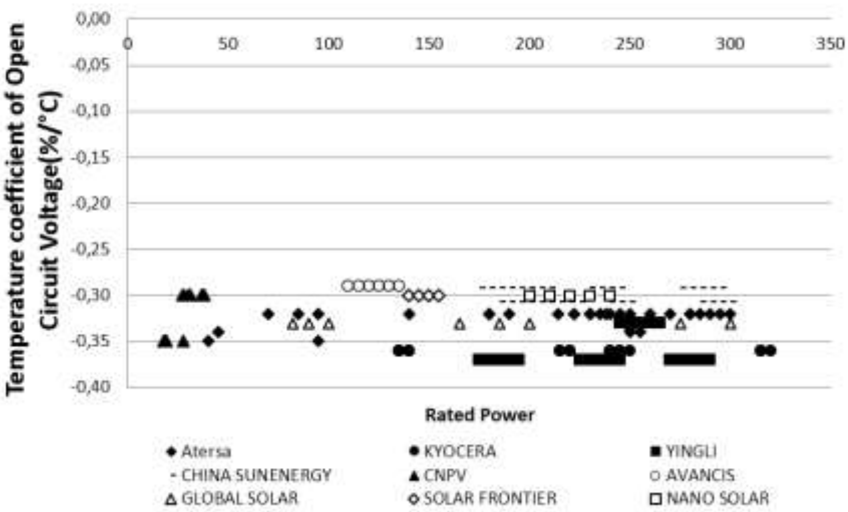

Fig. 11. Effect of temperature on the open circuit voltage.

Fig. 11 shows a greater dispersion of values. In general, the modules coefficients are situated in the range of -0.31 and -0.37 %/°C. In this case the mono and polycrystalline technologies present almost the same parameters as the thin film modules.

Conclusion

The main information obtained in this work is the analysis developed beyond the database collected. This information may be used in various studies on photovoltaic application, such as market characterization, references for typical values and technologies comparison.

This study intends to be a description of the photovoltaic market in 2012. As photovoltaic technology is in development phase, the variables mentioned here may have large variations in the coming years, which justifies the continuation of this work. Some of the adjustments can be done mainly adding new manufacturers, new technologies and other module types, such as the bifacial ones.

The main information obtained are related to the technical characteristics of current photovoltaic market, which can be used both for theoretical characterization technique and as a tool for project development, since it encompasses several important features in its application.

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